Sow Nutrition during Early Gestation

Subjects: Nutrition & Dietetics
Contributor: Pieter Langendijk

In the pig, the establishment and maintenance of luteal function in early gestation is crucial to endometrial function, embryo development, and survival. The level of feed intake has a positive effect on formation of luteal tissue and progesterone secretion by the ovaries in the pre-implantation period, which is important for endometrial remodeling and secretion. These effects are independent of luteinising hormone (LH) and probably driven by metabolic cues, such as insulin and insulin-like growth factor (IGF-1), and seem to support progesterone secretion and delivery to the endometrium, the latter which occurs directly, bypassing the systemic circulation. Even after implantation, a high feed intake seems to improve embryo survival and the maintenance of pregnancy. In this stage, luteal function is LH-dependent, although normal variations in energy intake may not result in pregnancy failure, but may contribute to nutrient supply to the embryos, since in this phase uterine capacity becomes limiting. Feed incidents, however, such as unintended fasting of animals or severe competition for feed, may result in embryo or even pregnancy loss, especially in periods of seasonal infertility. Specific nutrients such as arginine have a role in the vascularisation of the placenta and can improve the uterine capacity in the period after implantation.

Keywords: nutrition ; pigs ; gestation ; embryos

1. Introduction

The first 30 days of gestation are critical to the success of pregnancy in pigs. In this period, pregnancy is either established successfully or, when there is insufficient interaction between embryos and the uterus, the pregnancy is lost, or embryo survival is compromised. In this same period, the potential litter size is established, determined by the number of embryos that survive.

2. Focus of Nutrition: Establishment of Pregnancy, Embryo Survival, and Embryo Development

During the first month of gestation there are a number of processes and events that have a major impact on reproductive performance. Luteal tissue formation is critical to establish pregnancy and important to ensure an optimal uterine environment for the development, maintenance, and survival of embryos. At some stage, embryos start migrating, elongating, and implanting in the uterine horns, and during these developmental phases, embryos signal to the uterus. The communication between embryos and uterus is commonly referred to as ‘maternal recognition’, and ensures the maintenance of luteal tissue, sustained progesterone secretion, and pregnancy. As the litter of embryos goes through the various stages of development and implantation, a percentage will be lost due to embryo-intrinsic factors, the uterine environment, or to differences between embryos in development. These processes will be outlined briefly below, and in the second part of this paper, the interaction with nutritional effects will be examined.

2.1. Luteal Tissue Formation and Maintenance

The basis of a successful pregnancy and maximal embryo survival is the formation of ovarian luteal tissue, a process which is triggered by the preovulatory LH (luteinising hormone) surge causing luteinisation of the dominant follicles. In contrast to other species, porcine corpora lutea are maintained and remain critical for the whole duration of pregnancy, and luteolysis at any stage of pregnancy will result in loss of pregnancy. Porcine luteal tissue grows rapidly and gains maximum size between day 10 and 12 after ovulation, with a total luteal mass around 6 to 8 g in gilts and 10 to 15 g in multiparous sows [1]. The total luteal mass is correlated to the number of follicles that ovulate (correlation coefficient between 0.45 and 0.62; [2][3][4]), and therefore, older sows have more luteal tissue than gilts and primiparous sows. Embryos start secreting oestrogens at ~12 days, a signal for maternal recognition that ensures that luteolysis does not occur when it would normally occur in non-pregnant animals (day 14–15), and in doing so, maintain luteal function. If luteal tissue is maintained beyond day 12, the amount of tissue remains fairly stable during the remainder of the embryonic phase.

2.2. Progesterone, Prostaglandins, and Remodeling of the Endometrium

During the first month of pregnancy, systemic progesterone roughly follows the growth of the luteal tissue, increasing linearly until around day 12 after ovulation, then dropping slightly and levelling for the remainder of the embryonic phase [1]. The close match between the dynamics of the luteal tissue and progesterone underlines the importance of sufficient luteal tissue for establishment of pregnancy and for the control of the uterine environment.

Clearly, progesterone is important for the remodeling of the endometrial lining in order to facilitate the implantation and delivery of nutrients to the embryos. This is reflected in the correlation between embryo survival to day 35 ($r = 0.48$ [5]; $r = 0.72$ [6]) and systemic progesterone in the first three days of gestation. Beyond these first three days, progesterone does not seem to be correlated to embryo survival [3][7], suggesting that the level of progesterone is mainly limiting in the phase where it is still on the rise. At later stages progesterone receptors in the uterus seem to drop [8][9], which may indicate that the role of progesterone changes. Alternatively, in later stages, the level of progesterone may no longer be limiting.

Embryos signal their presence through the secretion of oestrogens, and in addition, through the secretion of PGE (prostaglandin E2). These factors redirect PGF (prostaglandin F2α) secretion away from the ovaries (where PGF would exert a luteolytic effect in the absence of pregnancy) and, in addition, render the luteal tissue less sensitive to PGF. In addition to these antiluteolytic effects, oestrogens and PGE also stimulate PGE secretion by the endometrium, and together with progesterone, initiate the remodling of the endometrium. These processes were comprehensively reviewed by Waclawik et al. [9], who also suggested that PGF has a dual role, switching from a luteolytic role in the absence of pregnancy to supporting the remodeling process in the endometrium in the presence of pregnancy. The combined effects of progesterone, PGFs, and PGEs result in a complex of inflammatory-like processes in the endometrium, involving growth factors such as VEGFs (vaso-endothelial growth factor), IGFs (insulin-like growth factor), TGFs (transforming growth factor), and EGFs (epidermal growth factor), which are involved in glandular formation, histotroph secretion, and angiogenesis [9]. The potential of nutritional interventions in these specific pathways have yet to be investigated.

2.3. Embryo Elongation, Maternal Recognition, and Embryo Survival

The majority of prenatal losses in pigs occur during the embryonic phase (before day 35), with 20 to 30% of embryos lost by day 21, and another 10 to 15% lost by day 35 [10]. It is generally assumed that in the case of proper oestrus detection and insemination conditions, close to 100% of oocytes are fertilised, and the resulting embryos will develop and reach the uterus by around day 5–6 after fertilisation.

Between day 8 and day 10, embryos, which are still ovoid at this stage, spread through the uterine horns where some will cross the bifurcation between the left and right horn. Between days 10 and 13, embryos elongate and space themselves along the uterine horns. At this stage, most embryos still survive (93–96%, [11]), and as they start secreting oestrogens and spacing, the embryos position themselves throughout the uterine horns, aligning themselves in preparation for implantation at around day 15 [12]. The process of spacing is a coordinated mechanism, during which the available uterine space is distributed fairly evenly among the embryos. Studies with inert, oestrogen-soaked beads have shown that this process may be facilitated by mild contractile activity of the uterus, induced by oestrogens originating from the embryos, with the presence of more or less embryos in specific areas of the uterus inducing more or less uterine contractility [13]. Spacing is independent of the number of embryos, and both small and large litters migrate and space evenly [14]. Whether there is direct communication between the embryos is not clear. From our own observations, implantation sites hardly ever overlap, which would suggest that there is. In the process of spacing and implantation, the developmental stage of the embryos and the variation between the embryos play a role in determining which embryos survive [15].

Before implantation, the variation in embryonic development may be such that advanced embryos influence the uterine environment in a way that is detrimental to more delayed embryos. Geisert et al. [16] showed that the treatment of sows with oestrogens before day 12 had a negative impact on embryonic survival. Embryos will still elongate, but do not survive to day 16 [17]. This suggests that there is a window before elongation, in which oestrogens are detrimental to embryonic development through their effect on the uterine environment, relative to the developmental stage of the embryos. Treatment with oestrogens at a later stage, when embryos start to secrete oestrogens themselves, does not appear harmful to embryonic survival [13]. Advanced embryos may start to secrete oestrogens at a stage when underdeveloped embryos are compromised by the same oestrogens, and this may be another mechanism through which variation in embryonic development causes embryonic mortality.

Experimental modifications of the uterine space per embryo by using superovulation [14], superinduction [18], ligation of uterine horns [19], hemi hystero-ovariectomy [20], and unilateral oviduct ligation [21] has shown that uterine space limits the survival of embryos to day 35 of gestation, hence the term uterine capacity. The timing of embryo loss, and what

limitations or factors drive these losses in different stages is important, however, only few studies provide information on these aspects. Some older studies in gilts suggest that 18 to 35% of embryos are lost to day 25, that these losses are mostly independent of space [12][22][23], and that uterine space only becomes limiting for survival after day 25.

More recent evidence in modern genotypes [24] demonstrates that around 40% of the embryos do not survive to day 35, and that two-thirds of the losses occur before day 21 in multiparous sows ovulating over 20 oocytes. By including a group of sows in which unilateral oviduct ligation was performed to provide more space per embryo, it was demonstrated that the losses before day 21 were unaltered and independent of space (Table 1). In both the intact sows and in the unilateral oviduct ligation model, 25% of embryos were lost by day 21. However, there were no embryo losses after day 21 in the unilateral oviduct ligation model, where embryos had ample space, whereas another 17% of embryos were lost after day 21 in the intact sows. Interestingly, the effect of uterine space was also evident from the length of the implantation sites and the embryo weight, which were 22% and 14% greater in the unilateral oviduct ligation model compared to the intact sows. This suggests that at or after implantation, competition between embryos for space results in mortality or reduced development of those embryos with insufficient space.

Table 1. Embryo survival and development at day 21 and day 35 of gestation in intact sows and in oviduct ligated sows, demonstrating the effect of uterine space (from Langendijk et al. [24]).

Item	Day 21 Intact Sows	Day 21 Oviduct Ligation *	Day 35 Intact Sows	Day 35 Oviduct Ligation *
Number of sows	**15**	**11**	**17**	**12**
Ovulations	**20.9 ± 1.5 ^{a}**	**11.6 ± 0.8 ^{b}**	**20.3 ± 0.9 ^{a}**	**10.7 ± 0.9 ^{b}**
Viable embryos, % **	**76 ± 5**	**75 ± 5**	**59 ± 4 ^{a}**	**77 ± 3 ^{b}**
Length of implantations, cm	**9.9 ± 1.1**	**11.4 ± 1.2**	**15.5 ± 1.3 ^{x}**	**19.0 ± 1.2 ^{y}**
Embryo weight, g	**0.22 ± 0.03**	**0.25 ± 0.05**	**4.3 ± 0.3 ^{x}**	**4.9 ± 0.2 ^{y}**

* Oviduct ligated sows had one oviduct ligated, limiting the number of fertilised oocytes entering the uterus to those originating from the patent oviduct. These embryos therefore, had twice the space compared to intact sows. ** Percentage of viable embryos: number of viable embryos present/number of ovulations at patent oviduct. ^{a,b} $p < 0.05$, ^{x,y} $p < 0.10$.

Collectively, this demonstrates that most (2/3) embryonic losses occur between days 12 and 21, around the time of implantation, and are not related to uterine capacity, but probably more to the variation between embryos in development as described above. One-third of embryo losses occur after day 21 and appear to be driven by the limitations of uterine capacity. These aspects need to be taken into account when considering the effects of nutrition on embryo survival and development, meaning that losses before and around implantation should be addressed by nutritional strategies that target the variation in embryo development, whereas losses after implantation should be addressed by nutritional strategies that target uterine capacity and functional space. This also means that nutritional strategies may require to differentiate between different windows of gestation, an approach that becomes feasible with today's precision feeding technology.

3. The Role of Nutrition in Luteal Tissue Formation, Progesterone, and Embryo Development Before Implantation

In pigs, apart from the LH surge that triggers ovulation, the growth of luteal tissue and the secretion of progesterone occur independent of LH, at least until 10–12 days after ovulation [25]. Effects of increased energy intake on LH that have been reported for other reproductive processes, such as for follicle development and the number of ovulations (e.g., [26]), would therefore not apply to luteal development in this early period of pregnancy. However, the formation of luteal tissue in this early period of the embryonic phase is affected by nutrition, both before and after ovulation.

The effects of nutrition before ovulation are evident from studies where feed restriction in the preceding luteal phase and follicular phase was applied to manipulate follicular dynamics (flushing). These studies were based on the principle that during periods of low energy intake or negative energy balance, endocrine cues that stimulate follicle development, such as FSH (follicle stimulating hormone) and LH, are suppressed directly at the hypothalamus–pituitary level, or indirectly through the effects of glucose and insulin regulation signaling at the ovarian level. In short, during the follicular phase, when late antral follicles are selected to become the dominant and ovulatory pool of follicles (e.g., [26]), but also earlier during the luteal phase in gilts, or during lactation in weaned sows (e.g., [6]). When early antral follicles are recruited to

develop into late antral follicles, restricted energy intake suppresses follicle development with lower ovulation rates as a result.

In more recent studies, feed restriction in cyclic gilts during the preceding luteal or follicular phase has been shown to have negative carry over effects on the rise in peripheral progesterone after ovulation [2][27], with some of these effects being due to reduced formation of luteal tissue [28]. Similarly, feed restriction in primiparous sows during the lactation preceding post-weaning ovulation, reduces post-ovulatory luteal function and progesterone [29]. The administration of insulin can counteract these effects in vivo [2] and results in increased progesterone secretion in vitro [30], suggesting that insulinogenic diets would support the formation of luteal tissue and the secretion of progesterone. In that respect, it is interesting to note that lactation diets rich in fast carbohydrates (starch and sugar) increased peripheral progesterone post ovulation [31], and that in post-weaning multiparous sows, pre-ovulatory blood insulin levels were correlated with post-ovulatory progesterone [32].

These examples illustrate how energy intake and insulinogenic ingredients that affect follicular dynamics, may benefit post-ovulatory luteal development and function. This may be through carry over effects of pre-ovulatory diets on the quality of the luteal tissue, and through effects on the amount of luteal tissue due to an increased ovulation rate.

Nutritional interventions during the post-ovulatory period can also affect the formation of luteal tissue and progesterone secretion (Table 2). In both gilt and multiparous sow models, feed restriction during early gestation reduced the amount of luteal tissue at day 30–35 of gestation [3][7], but also as early as day 10 after ovulation [33]. Considering that up to day 10–12 of pregnancy the formation of corpora lutea is LH-independent, the effects of nutrition in this early period are more likely to be mediated by other factors. Similar to premating nutrition, post-mating effects on luteal function may be mediated by insulin or insulin-related pathways such as IGF-1. Both insulin and IGF-1 are higher in gilts fed at a high feeding level in early pregnancy [34][35]. IGF-1 stimulates progesterone secretion by luteal tissue in vitro [36] and in vivo [37] and supports luteal tissue formation [38]. In primiparous sows, Langendijk et al. [39] reported a correlation between IGF-1 and post-ovulatory progesterone. Collectively, these data point to a role of feed or energy intake in growth of luteal tissue and the secretion of progesterone, and would suggest that insulin and IGF-1 stimulating dietary strategies would enhance luteal development in early pregnancy.

Table 2. Effects of feed allowance (high or low) in early pregnancy on the amount of luteal tissue.

Reference	Feed Allowance (High vs. Low *)	Duration of Treatments	Luteal Tissue Mass, g		Stage of Gestation
			High	Low	
[3]	2.4 vs. 1.2 M	d1–25	7.2 ^{a}	6.7 ^{b}	d35
[7]	+2.5 kg	d1–7	9.5 ^{a}	7.7 ^{b}	d30
[33]	2.4 vs. 1.2 M	d1–10	8.2	7.9	d10
[26]	2.4 vs. 0.8 M	-	No effect	-	-

* Feed allowance expressed as kg or relative to maintenance requirements (M). ^{a,b} $p < 0.05$.

References

1. Langendijk, P.; Peltoniemi, O. How does nutrition influence luteal function and early embryo survival. Soc. Reprod. Ferti l. 2013, 68, 145–158.
2. Almeida, F.R.C.L.; Mao, J.; Novak, S.; Cosgrove, J.R.; Foxcroft, G.R. Effects of different patterns of feed restriction and insulin treatment during the luteal phase on reproductive, metabolic, and endocrine parameters in cyclic gilts. J. Anim. Sci. 2001, 79, 200–212.
3. Athorn, R.Z.; Stott, P.G.; Bouwman, E.G.; Edwards, A.C.; Blackberry, M.A.; Martin, G.B.; Langendijk, P. Feeding level a nd dietary energy source have no effect on embryo survival in gilts, despite changes in systemic progesterone levels. A nim. Prod. Sci. 2013, 53, 30–37.
4. Willis, H.J.; Zak, L.J.; Foxcroft, G.R. Duration of lactation, endocrine and metabolic state, and fertility of primiparous so ws. J. Anim. Sci. 2003, 81, 2088–2102.
5. Foxcroft, G.R. Mechanisms mediating nutritional effects on embryonic survival in pigs. J. Reprod. Fertil. 1997, 1, 47–6 2.

6. Zak, L.J.; Williams, I.H.; Foxcroft, G.R.; Pluske, J.R.; Cegielski, A.J.; Clowes, E.J.; Aherne, F.X. Feeding lactating primiparous sows to establish three divergent metabolic states: I. Associated endocrine changes and postweaning reproductive performance. J. Anim. Sci. 1998, 76, 1145–1153.
7. Gerritsen, R.; Soede, N.M.; Laurenssen, B.; Langendijk, P.; Dieleman, S.J.; Hazeleger, W.; Laurenssen, B.F.A.; Kemp, B. Feeding level does not affect progesterone levels in intermittently suckled sows with lactational ovulation. Anim. Reprod. Sci. 2008, 103, 379–384.
8. Steinhauser, C.B.; Bazer, F.W.; Burghardt, R.C.; Johnson, G.A. Expression of progesterone receptor in the porcine uterus and placenta throughout gestation: Correlation with expression of uteroferrin and osteopontin. Domest. Anim. Endocrinol. 2017, 58, 19–29.
9. Waclawik, A.; Kaczmarek, M.M.; Blitekl, A.; Kaczynski, P.; Ziecik, A.J. Embryo-maternal dialogue during pregnancy establishment and implantation in the pig. Mol. Reprod. Dev. 2017, 84, 842–855.
10. Ford, S.P.; Vonnahme, K.A.; Wilson, M.E. Uterine capacity in the pig reflects a combination of uterine environment and conceptus genotype effects. J. Anim. Sci. 2002, 80, E66–E73.
11. Anderson, L.H.; Christenson, L.K.; Christenson, R.K.; Ford, S.P. Investigations into the control of litter size in swine: II. Comparisons of morphological and functional embryonic diversity between Chinese and American breeds. J. Anim. Sci. 1993, 71, 1566–1571.
12. Dziuk, P. Effect of migration, distribution and spacing of pig embryos on pregnancy and fetal survival. J. Reprod. Fertil. 1985, 33, 57–63.
13. Pope, W.F.; Lawyer, M.S.; First, N.L. Intrauterine migration of the porcine embryo: Coordination of bead migration with estradiol. J. Anim. Sci. 1986, 63, 848–853.
14. Dziuk, P.J. Effect of number of embryos and terine space on embryonic survival in the pig. J. Anim. Sci. 1968, 27, 673–676.
15. Geisert, R.D.; Schmitt, R.A.M. Early embryonic survival in the pig: Can it be improved? J. Anim. Sci. 2002, 80, E54–E65.
16. Geisert, R.D.; Ross, J.W.; Ashworth, M.D.; White, F.J.; Johnson, G.A.; Da Silva, U. Maternal recognition of pregnancy or endocrine disruptor: The two faces of oestrogen during establishment of pregnancy in the pig. Soc. Reprod. Suppl. 2006, 62, 131–145.
17. Morgan, G.L.; Geisert, R.D.; Zavy, M.T.; Fazleabas, A.T. Development and survival of pig blastocysts after oestrogen administration on day 9 or days 9 and 10 of pregnancy. J. Reprod. Fertil. 1987, 80, 133–141.
18. Rampacek, G.R.; Robison, O.W.; Ulberg, L.C. Uterine Capacity and Progestin Levels in Superinducted Gilts. J. Anim. Sci. 1975, 41, 564–567.
19. Chen, Z.Y.; Dziuk, P.J. Influence of initial length of uterus per embryo and gestation stage on prenatal survival, development, and sex ratio in the pig. J. Anim. Sci. 1993, 71, 1895–1901.
20. Père, M.C.; Dourmad, J.-Y.; Etienne, M. Effect of number of pig embryos in the uterus on their survival and development and on maternal metabolism. J. Anim. Sci. 1997, 75, 1337–1342.
21. Town, S.C.; Putman, C.T.; Turchinsky, N.J.; Dixon, W.T.; Foxcroft, G.R. Number of conceptuses in utero affects porcine fetal muscle development. Reproduction 2004, 128, 443–454.
22. Pope, C.E.; Christenson, R.K.; Zimmerman-Pope, V.A.; Day, B.N. Effect of number of embryos on embryonic survival in recipient gilts. J. Anim. Sci. 1972, 35, 805–808.
23. Webel, S.K.; Dziuk, P.J. Effect of stage of gestation and uterine space on prenatal survival in the pig. J. Anim. Sci. 1974, 38, 960–963.
24. Langendijk, P.; Chen, T.Y.; Athorn, R.Z.; Bouwman, E.G. Embryonic survival at day 9, 21 and 35 of pregnancy in intact and unilaterally oviduct ligated multiparous sows. Animal 2016, 10, 1336–1341.
25. Peltoniemi, O.A.T.; Easton, B.G.; Love, R.J.; Klupiec, C.; Evans, G. Effect of chronic treatment with a GnRH agonist (Goserelin) on LH secretion and early pregnancy in gilts. Anim. Reprod. Sci. 1995, 40, 121–133.
26. Quesnel, H.; Pasquier, A.; Mounier, A.-M.; Prunier, A. Feed restriction in cyclic gilts: Gonadotrophin-independent effects on follicular growth. Reprod. Nutr. Dev. 2000, 40, 405–414.
27. Chen, T.Y.; Stott, P.; Athorn, R.Z.; Bouwman, E.G.; Langendijk, P. Undernutrition during early follicle development has irreversible effects on ovulation rate and embryos. Reprod. Fertil. Dev. 2012, 24, 886–892.
28. Ashworth, C.J.; Beattie, L.; Antipatis, C. Effects of pre- and post-mating nutritional status on hepatic function, progesterone concentration, uterine protein secretion and embryo survival in meishan pigs. Reprod. Fertil. Dev. 1999, 11, 67–73.

29. Mao, J.; Zak, L.J.; Cosgrove, J.R.; Shostak, S.; Foxcroft, G.R. Reproductive, metabolic, and endocrine responses to fe ed restriction and gnrh treatment in primiparous, lactating sows. J. Anim. Sci. 1999, 77, 724–735.
30. Mao, J.; Treacy, B.K.; Almeida, F.R.C.L.; Novak, S.; Dixon, W.T.; Foxcroft, G.R. Feed Restriction and Insulin Treatment Affect Subsequent Luteal Function in the Immediate Postovulatory Period in Pigs: Progesterone Production In Vitro and Messenger Ribonucleic Acid Expression for Key Steroidogenic Enzymes. Biol. Reprod. 2001, 64, 359–367.
31. Chen, T.Y.; Stott, P.; Bouwman, E.G.; Langendijk, P. Effects of Pre-Weaning Energy Substitutions on Post-Weaning Foll icle Development, Steroid Hormones and Subsequent Litter Size in Primiparous Sows. Reprod. Domest. Anim. 2013, 4 8, 512–519.
32. Wientjes, J.G.M.; Soede, N.M.; van den Brand, H.; Kemp, B. Nutritionally induced relationships between insulin levels d uring the weaning-to-ovulation interval and reproductive characteristics in multiparous sows: II. Luteal development, pro gesterone and conceptus development and uniformity. Reprod. Domest. Anim. 2011, 47, 62–68.
33. Athorn, R.Z.; Stott, P.; Bouwman, E.G.; Chen, T.Y.; Kennaway, D.J.; Langendijk, P. Effect of feeding level on luteal funct ion and progesterone concentration in the vena cava during early pregnancy in gilts. Reprod. Fertil. Dev. 2012, 25, 531 –538.
34. Ferguson, E.M.; Ashworth, C.J.; Edwards, S.A.; Hawkins, N.; Hepburn, N.; Hunter, M.G. Effect of different nutritional re gimens before ovulation on plasma concentrations of metabolic and reproductive hormones and oocyte maturation in gi lts. Reproduction 2003, 126, 61–71.
35. Novak, S.; Treacy, B.K.; Almeida, F.R.C.L.; Mao, J.; Buhi, W.C.; Dixon, W.T.; Foxcroft, G.R. Regulation of IGF-I and por cine oviductal secretory protein (pOSP) secretion into the pig oviduct in the peri-ovulatory period, and effects of previou s nutrition. Reprod. Nutr. Dev. 2002, 42, 355–372.
36. Ptak, A.; Gregoraszczuk, E.L.; Rzasa, J. Growth hormone and insulin-like growth factor-I action on progesterone secret ion by porcine corpora lutea isolated at various periods of the luteal phase. Acta Vet. Hung. 2003, 51, 197–208.
37. Miller, E.A.; Ge, Z.; Hedgpeth, V.; Gadsby, J.E. Steroidogenic responses of pig corpora lutea to insulin-like growth facto r I (IGF-I) throughout the oestrous cycle. Reproduction 2003, 125, 241–249.
38. Ptak, A.; Kajta, M.; Gregoraszczuk, E.L. Effect of growth hormone and insulin-like growth factor-I on spontaneous apopt osis in cultured luteal cells collected from early, mature, and regressing porcine corpora lutea. Anim. Reprod. Sci. 2004, 80, 267–279.
39. Langendijk, P.; van den Brand, H.; Gerritsen, R.; Quesnel, H.; Soede, N.M.; Kemp, B. Porcine luteal function in relation to IGF-1 levels following ovulation during lactation or after weaning. Reprod. Domest. Anim. 2008, 43, 131–136.